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**METHOD AND APPARATUS FOR DRY ETCHING
AND ELECTROSTATIC CHUCKING DEVICE
USED THEREIN**

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method and an apparatus for dry etching and, an electrostatic chucking device used for said etching method, and in detail, a method and an apparatus for effectively controlling the temperature of a material to be etched when dry etching is performed by using either a plasma etching apparatus, a sputter etching apparatus or a reactive sputter etching apparatus, and, an electrostatic chucking device used for said dry etching method for holding and fixing the material during etching and for controlling the temperature of the material. The method and apparatus according to the present invention can be used for the production of, for example, semiconductor integrated circuits.

2. Description of the Prior Art

Dry etching is a technique by which materials such as Si, SiO₂, Si₃N₄, Al, W, Mo, Ti and the alloys of these metals and the like are etched either a plasma etching apparatus, a sputter etching apparatus or a reactive sputter etching apparatus. Particularly the dry etching technique has the following advantages over liquid etching:

- (I) optically sensitive resin can be used as an etching mask,
- (II) the undercut of the material to be etched is small, thus a finer profiled pattern can be formed at the etching,
- (III) the contamination by impurities found in the liquid etching method can be protected against.
- (IV) the etching control characteristic is excellent, and is more widely used than the liquid etching method.

To increase production on a production line, using etching, an increased etching speed is desired. However in order to try to increase the speed of the dry etching, the applied electric but must be high power, the generating heat caused by the plasma discharge is also increased and when the temperature of the material to be etched is raised to approximately 100 degrees centigrade, deterioration or melting of the resist, which is used for the mask, occurs and normal etching cannot be performed. The above-mentioned problems have remained unsolved. These problems are more pronounced in sputter etching or reactive sputter etching in which the material to be etched is subjected to ion impingement. Therefore, in order to increase production using these methods it is necessary to cool the material to be etched.

Contrary to the above-mentioned example concerning overheating, in some cases the high temperature of the material to be etched is advantageous. An example, is the case in which the vapor pressure of the reaction products is extremely low at the normal temperature created by plasma etching or reactive sputter etching. During etching it is generally necessary to remove the reaction products quickly. Therefore, in the above-mentioned case, it is advantageous to increase the vapor pressure of the reaction products by raising the temperature of the material to be etched, and for this reason sometimes the supporting base of the material is heated.

However, merely resting the material to be etched on the supporting base which is temperature controlled, is

not sufficient. A close contact for thermal conduction is further desired so that the temperature of the supporting base can be conducted to the material to be etched with high conductivity. For example, when the material to be etched is a semiconductor wafer, the wafer has warps the lengths of which are tens of micrometers, therefore, to improve conductivity the wafer must be pressed, the warps must be corrected and the contact area must be increased. In addition, in the case of etching aimed at fine profiled processing, the adherence of dust to the material to be etched causes serious problems. To avoid these problems it is preferable that the material to be etched, if possible, be held invertedly in the horizontal plane; or vertically during etching.

The method of holding and fixing the object, the so called method of chucking, usually makes use of a mechanical chuck. When use of a mechanical chuck cannot be made or is not desirable, a method using a vacuum chuck, an electrostatic chuck or the like are known. The electrostatic chuck technique is a method based on the principle of electrostatic attracting force and is preferred for material to be etched which are comparatively light and require treatment in a vacuum condition.

The electrostatic chuck is particularly useful in the semiconductor device producing process. For example, processes such as vacuum evaporation, chemical vapor deposition (CVD), etching or the like are performed under a vacuum condition or extremely low air pressure, therefore, the vacuum chuck cannot be used.

The mechanical chuck, no matter what form the chuck takes, must cover a part of the wafer by means of the arm of the chuck and at that part of wafer the semiconductor device cannot be produced. The mechanical chuck applies the force for holding to only a portion of the wafer, thus it is inadequate to accomplish the object of reforming and making flat the warps by pressing. Thus, the mechanical chuck method is also not a desirable method.

The electrostatic chuck can be used under the vacuum condition, it needs no arm to hold the processing material, and the holding force can be applied uniformly. Thus, the electrostatic chuck method has many advantages in the semiconductor device producing processes.

As electrostatic chucks, i.e., electrostatic chucking devices, the following two types are known. One of these electrostatic chucking devices, as shown in FIG. 1, has a plane electrode 1 on which a material to be chucked 3 is located and an insulator 2 inserted therebetween. Voltage is applied between the electrode 1 and the material to be chucked 3, whereby the material to be chucked 3 is attracted. The attracting force F is shown by the following equation (1);

$$F = \frac{1}{4} \cdot \epsilon \cdot \frac{V^2}{d^2} \cdot S \quad (1)$$

Where, ϵ is the dielectric constant, V is the applied voltage, d is the thickness of the insulator layer, and S is the area of the electrode.

In this method, since the voltage is applied between the material to be chucked 3 and the electrode 1, electrical contact with the material to be chucked is required. For this reason, the material to be chucked 3 is limited to conductors, semiconductors, or at least a material covered with a conductive material on the surface

thereof. Therefore, a semiconductor wafer covered with an insulator such as SiO₂ film cannot be treated using the above mentioned method.

The other whom electrostatic chuck example is shown in FIGS. 2 and 3. This example has electrodes 4 and 5 which are comb-shaped and intricated with each other, and the material to be chucked 3' is located on the electrodes 4 and 5 with the insulator 2 inserted therebetween. This type of electrostatic chuck is a device which attracts an insulator such as a sheet of paper. In this example, since the interval space between the pair of electrodes is designed to be extremely narrow, a strong electric field is generated between the electrodes. In this method the attractive force is produced between the polarized charges, i.e., the charge induced on the material to be chucked 3', and the other side charge which appears on the electrodes. This method is also used for chucking non-conductive materials, thus it has a wider application than the attracting force in the method of FIG. 1, however the attracting force is weaker.

The principle of the electrostatic chucking device according to the present invention is explained below. Reference is first made to FIGS. 5 and 10; FIG. 10 is an electrically equivalent circuit of the circuit in FIG. 5. Since the material to be chucked 3 is conductive, the electrostatic capacities C1 and C2 exist between the material to be chucked 3 and the electrodes 4 and 5, respectively, and the material to be chucked and the electrodes can be considered condensers. These condensers are connected in series through the lines illustrated in FIG. 5 and the material to be chucked 3.

If the electrical potential of the electrodes 4 and 5 is V1 and V2, respectively, and the electrical potential of the material to be chucked is V12, V12 is shown by the following equation:

$$V_{12} = \frac{C_1}{C_1 + C_2} V_1 + \frac{C_2}{C_1 + C_2} V_2 \quad (2)$$

It is known that when the voltage is applied across the condenser, the electrostatic force operates between the electrodes of the condenser, and the value of this electrostatic force is expressed in the equation (1). Since the voltage being applied across the condenser C1 and C2 are (V12-V1) and (V12-V2), respectively, the electrostatic attracting force F(C1, C2) is shown by the following equation (where S1 and S2 are electrode areas of the condensers C1 and C2, respectively):

$$F(C_1, C_2) = \frac{1}{d^2} \left\{ (V_{12} - V_1)^2 S_1 + (V_{12} - V_2)^2 S_2 \right\} \quad (3)$$

Using the relations

$$C_1 = \frac{\epsilon S_1}{d}, \quad C_2 = \frac{\epsilon S_2}{d} \quad (4)$$

and equation (2), F(C1, C2) is then shown by the following equation (5):

$$\begin{aligned} F(C_1, C_2) &= \frac{1}{d^2} \frac{S_1 S_2}{S_1 + S_2} (V_2 - V_1)^2 \\ &= \frac{1}{d^2} \frac{S_1 S_2}{S_1 + S_2} V^2 \end{aligned} \quad (5)$$

where $V = |V_1 - V_2|$

As can be understood from the equation (5), the attracting force is proportional to the dielectric constant, the area of the electrode, and the square of the voltage, but is inversely proportional to the square of the insulator thickness. F(C1, C2) becomes maximum when

$$S_1 = S_2 = \frac{S_1 + S_2}{2} = \frac{S}{2},$$

and in this case F(C1, C2) is shown as the equation (7):

$$F(C_1, C_2) = \frac{\epsilon}{8} \cdot \frac{V^2}{d^2} \cdot S \quad (7)$$

The present invention applies the above mentioned principle in order to solve the problems in the conventional method and apparatus for dry etching, and the conventional electrostatic chucking device.

SUMMARY OF THE INVENTION

One object of the present invention is to provide an electrostatic chucking device which can be applied to electrically conductive materials such as a semiconductor wafer including conductor and semiconductor, and to electrically conductive materials covered with a thin insulating film on the surface thereof, and which chucking device has a stronger attracting force and a more simple structure than known in the art.

Another object of the present invention is to provide a method and an apparatus for dry etching which can indirectly chuck the material to be etched to the supporting base and make the supporting base highly heat conductive by using the electrostatic chucking device to hold and fix the material to be etched during dry etching (either plasma etching, sputter etching or reactive sputter etching, and thereby allowing the temperature of the material to be etched to be controlled effectively and the material to be etched to be held invertibly in the horizontal plane or vertically).

According to one aspect of the present invention, there is provided an electrostatic chucking device positioned on a supporting base, the temperature of which can be maintained at a predetermined value, the electrostatic chucking device comprising a sheet of insulator supporting base, and a pair of plane electrodes being electrically isolated from each other and being positioned on the bottom surface of said sheet of insulator in close contact therewith, and an external power source which supplies a voltage between said plane electrodes so that said material can be chucked on said sheet of insulator. The device is capable of chucking a material having at least a conductive portion thereon, wherein the sum of the area of the portions of said pair of plane electrodes facing the direction of said material is approximately equal to the contact area between said material and said sheet of insulator when said material is chucked.

According to another aspect of the present invention, there is provided a method for dry etching of a material having at least a conductive portion therein, using at least one of the following: a sputter etching apparatus, a reactive support etching apparatus or a plasma etching apparatus, and comprising the steps of: putting the material to be etched on electrostatic device which is mounted on a supporting base, the temperature of which is maintained at a predetermined value, the elec-

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trostatic device comprises a sheet of insulator, and a pair of plane electrodes being electrically isolated from each other and being positioned on the bottom surface of said sheet of insulator in close contact therewith, and an external power source which supplies a voltage between said plane electrodes, so that the material can be chucked on said sheet of insulator, and wherein the sum of the area of the portions of said pair of plane electrodes facing the direction of said material is approximately equal to the contact area between said material and said sheet of insulator when said material is chucked; applying the voltage between said pair of plane electrodes of the electrostatic device from the external power source, and thereby, causing said material to be chucked, and therefore indirectly fixed electrostatically to said supporting base for etching by etching gases in the etching chamber of the sputter etching apparatus, the reactive sputter etching apparatus or the plasma etching apparatus.

According to a further aspect of the present invention, there is provided an apparatus for dry etching a material having at least a conductive portion therein and using at least a sputter etching apparatus, a reactive sputter etching apparatus or a plasma etching apparatus, comprising: a supporting base, the temperature of which is maintained at a predetermined value, an electrostatic chuck mounted on the supporting base for chucking said material, the electrostatic chuck comprises a sheet of insulator and a pair of plane electrodes being electrically isolated from each other and being positioned on the bottom surface of said sheet of insulator in close contact with said sheet, wherein the sum of the portion of the area of said pair of plane electrodes facing said material being approximately equal to the contact area between said material and said sheet of insulator when said material is chucked, and a voltage from an external power source being applied between said pair of plane electrodes, so that said material can be chucked on said sheet of insulator.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side view illustrating one conventional electrostatic chuck device;

FIG. 2 is a plan view illustrating another example of a conventional electrostatic chucking device;

FIG. 3 is a cross-sectional view taken along the line III-III of FIG. 2 showing an electrostatic chucking device;

FIG. 4 is a diagrammatic view illustrating the preferred embodiment of the present invention using a reactive sputter etching apparatus;

FIG. 5 is a side view illustrating an electrostatic chucking device according to an embodiment of the present invention;

FIG. 6 is a detailed view of the device of FIG. 5;

FIG. 7 is a plan view taken along the line VII-VII of the device in FIG. 6;

FIG. 8 is a plan view of electrodes of an electrostatic chucking device according to another embodiment of the present invention;

FIG. 9 is a plan view of electrodes of an electrostatic chucking device according to a further embodiment of the present invention;

FIG. 10 is an equivalent circuit diagram of the electrostatic chucking device of FIG. 5.

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DESCRIPTION OF THE PREFERRED EMBODIMENTS

Below, embodiments of the present invention is explained using FIGS. 4-10.

FIG. 5 is a cross-sectional view and wiring diagram of an electrostatic chucking device according to the present invention. The plan view of electrodes in the electrostatic chucking device in FIG. 5 is shown in FIG. 7. A material to be chucked 3 can be attracted by applying approximately 1000 to 5000 volts between a pair of plane electrodes 4 and 5. For example, electrodes made of aluminum can be used as electrodes 4 and 5, an insulator made of material such as polytetrafluoroethylene or polyethylene can be used as the insulator 2, and preferably the thickness d of the insulator 2 is approximately 50 to 200 micrometers.

[Experiment 1]

The performance of the following electrostatic chucking devices is compared, namely, a conventional device (1) as depicted in FIG. 1, a conventional device (2) as depicted in FIG. 2, and a device according to the present invention, by referring to the results of the experiment hereinbelow. In the devices used for the experiment, the area of the chucking portion is 100 square centimeters and the thickness of the insulator is 100 micrometers. Polyethylene is used as the material of the insulators, and alumina plates, silicon wafers, silicon wafers with SiO₂ film of 1 micrometer on the surface and quartz plates are used as the materials to be chucked. An applied voltage is 1000 volts.

The results of the above mentioned experiment regarding the electrostatic chucking devices are shown in following table:

TABLE

Electrostatic chucking device	Electrostatic chucking force (gram-weight)			
	The material to be etched			
	Al plate	Si wafer	Si wafer + SiO ₂	Quartz plate
Conventional ex. (1)	1130	1210	0	0
Conventional ex. (2)	140	130	130	20
Present invention	310	290	310	0

Conventional ex. (1): Device in FIG. 1

Conventional ex. (2): Device in FIG. 2

It is found from the table that the electrostatic chucking device according to the present invention can be used for etching conductors, semiconductors, and conductors and semiconductors covered with a thin insulating film on the surface. The attracting force of the electrostatic chucking device according to the present invention is weaker than the attracting force of the conventional electrostatic chucking device in FIG. 1; however, it is about twice as strong as the conventional electrostatic chucking device of FIG. 2 and 3. According to the above mentioned characteristics, the electrostatic chucking device according to the present invention is the most advantageous of the above three examples as an electrostatic chucking device for treating a semiconductor wafer covered with insulating film, such as SiO₂ or Si₃N₄ films, and also facilities manufacturing the device since the structure of the device is simple.

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In FIGS. 8 and 9, other embodiments of the electrostatic chucking device according to the present invention are shown. In these embodiments, the shapes of the electrodes are changed from the shape of the electrodes in FIG. 7. The shape of the electrodes in FIG. 8 is divided into four parts and electrodes 6 and 7 are symmetrical about a center point, and in FIG. 9, an example having concentric-form electrodes 8 and 9 is shown.

FIG. 4 is a diagrammatic view of a reactive sputter etching apparatus 10 using generally the method for dry etching according to the present invention. In FIG. 4 an anode 11 is grounded and a cathode 12 is supplied with high frequency voltage (r.f.) through a condenser 13, and then etching is performed. The material to be etched 14 is attracted to the cathode 12 by an electrostatic chucking device 16. Namely, the cathode 12 is also the supporting base of the material to be etched 14, and the cathode or the supporting base 12 has either a water jacket 15 to keep the base cool with water or an appropriate electric heater to heat the base, as well as the electrostatic chucking device 16 having a pair of plane electrodes. The arrows in the Figure indicate the direction of gas flow.

The electrostatic chucking device 16 includes a pair of plane electrodes 17 and 18 as shown by the sectional and plan view in FIGS. 6 and 7, respectively. For example, by the electric wiring as shown in FIG. 6, a voltage of approximately 1000 through 2000 volts is applied between the electrodes 17 and 18, and the material to be etched 14 is indirectly clamped to the supporting base 12 electrostatically. Then the heat conductivity between the material to be etched 14 and the supporting base 12 is increased. The electrode plate 16 is constructed, for example, with aluminum electrodes 17 and 18 buried in an insulating layer 19 made of silicon gum.

The thickness of the first layer of the insulating layer 19 is preferably approximately 0.05 through 0.2 mm. The insulating layer 19 desirably has elasticity so that the insulating layer 19 can contact closely with the material to be etched. The resistors in the electric wiring of FIG. 6 are filters and prevent the high frequency electric field from being lost through the external power source circuit or, in other words, from being shielded by the plane electrodes of the electrostatic chucking device. The resistant value must be determined sufficiently higher than plasma impedance. Instead of electrical resistance, coils can be used, and the impedance of the coil must be determined similarly as in the case of resistance. In FIG. 6 the reference numeral 20 shows a power switch and the reference numeral 21 shows a switch for leaking.

[Experiment 2]

In order to explain the effect of the method for dry etching according to the present invention, the results of an experiment using silicon wafers as the material to be etched in the apparatus of FIG. 4 are explained below.

The experiment was performed using the following steps. In the quartz chamber a silicon wafer is arranged as shown in FIG. 4, sputter etching or reactive sputter etching is started, and after initiating the discharge the temperature of the wafer is measured. Where the generating heat quantity becomes equal to the loss of heat, namely the temperature of the wafer is at equilibrium, the temperature of the wafer is obtained when using and also when not using the electrostatic chucking device.

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The electrostatic chucking device used in experiment 2 has a pair of plane electrodes, made of aluminum as shown in FIGS. 6 and 7, and polytetrafluoroethylene having a thickness of 0.1 mm is coated as an insulating layer on the surface of the electrodes. The results obtained from the experiment are as follows:

Sputter etching condition: Argon 13.33 Pa (0.1 Torr)
Applied electric power: 300 watts

- 10 (a) Balancing temperature of the wafer with an electrostatic chucking device: 50 degrees centigrade
- (b) Balancing temperature of the wafer without an electrostatic chucking device: 230 degrees centigrade

15 In a further experiment using the apparatus in FIG. 4 aluminum was etched with CCl₄.

Etching condition: CCl₄ 13.33 Pa (0.1 Torr), applied electric power 800 watts

20 In the above described condition using the electrostatic chucking device 16, the aluminum could be etched at the high etching rate of 3 micrometers/minutes. However, if the electrostatic chucking device 16 is not used, when the applied electric power rises to at least 200 watts or above, the resist film on the wafer is destroyed because of high temperature caused by the high density of plasma excited thereby, and the etching rate must be decreased to approximately 0.3 micrometers/minutes.

[Experiment 3]

30 Examples of the present invention being applied to barrel type plasma etching or microwave excited plasma etching are explained below. In these examples a wafer is located on a supporting base cooled by water, an electrostatic chucking device was inserted therebetween and was etched under the condition of Argon 13.33 Pa (0.1 Torr) and an applied electric power of 300 watts by a barrel type plasma etching process, and then the temperature of the wafer was balanced at 35 degrees centigrade. In the case without the electrostatic chucking device, the temperature of the wafer rises to 120 degrees centigrade.

35 In both the microwave excited plasma etching and the barrel type plasma etching, an excellent cooling effect was obtained by the method for dry etching according to the present invention as shown below:

40 Etching condition: Argon 13.33 Pa (0.1 Torr); applied electric power 300 watts

- (a) Balancing temperature of the wafer with an electrostatic chucking device: 60 degrees centigrade
- (b) Balancing temperature of the wafer without an electrostatic chucking device: 230 degrees centigrade

45 As explained above, according to the present invention, the great amount of heat being generated at the wafer can be removed effectively, allowing thereby the high rate of etching by the high electric power to be performed by sputter etching, reactive sputter etching or plasma etching. Further, the method according to the present invention can be applied when either conductive materials, semiconductors or the insulating film on these materials are to be etched. Also, the method can be applied when either the material to be etched is treated on the anode, the cathode or any portion in the plasma. Moreover, said electrostatic chucking device can be used both in plasma and in a vacuum atmosphere.

50 When it is desired that the material to be etched be located vertically invertedly in the horizontal plane, the electrostatic chucking device is located on the support-

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ing base, and the material to be etched is then put on the electrostatic chucking device after the voltage is applied to the electrostatic chucking device and the material to be etched is indirectly chucked to the supporting base, the location of the material to be etched can be regulated by the rotation of 90 degrees or 180 degrees of the electrode portion in the dry etching apparatus. By using the above-mentioned procedure, defects in the etched pattern due to the dust can be decreased considerably.

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[Experiment 4]

In this experiment, the etching of an Aluminum-Copper (Al-Cu) alloy was attempted. The method of the experiment is explained below. The etching was performed using the etching apparatus in FIG. 4 heated with a heater at the electrode temperature of approximately 250 degrees centigrade. The heater was provided in the supporting base so that the nichrome wire of the heater was insulated from the supporting base with a ceramic such as alumina. In order not to transmit the high frequency electric power to the nichrome wire, it is recommended that the voltage be applied to the heater as well as to the electrostatic chucking device through coils. SiO₂ was used as an etching mask, and CCl₄ was used as the etching gas.

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Comparing the result from the apparatus having the heater with an electrostatic chucking device with the result from the apparatus having no heater, a granular residue remained on the material to be etched in the case of using no heater, whereas in the case of using a heater, the granular residue could not be found. This fact is explained according to the following consideration. Namely, it is supposed that the Al-Cu alloy is etched due to the following reactions:



Also it is supposed that since the vapor pressure of CuCl₂ is very low, Cu or CuCl₂ remains as residue if the temperature of the material to be etched is not raised by heating. Thus, using the heater with an electrostatic chucking device advantageously minimizes residue.

I claim:

1. An electrostatic device for chucking a material having at least a conductive portion, comprising:
 - (a) a sheet of insulator;
 - (b) a pair of plane electrodes positioned on the bottom surface of said sheet of insulator in close contact with said sheet, wherein
 - (i) said pair of plane electrodes is electrically isolated from each other,
 - (ii) voltage being supplied between said pair of plane electrodes from an external voltage source, such that said plane electrodes are capable of chucking the conductive material on the top surface of said sheet of insulator, and
 - (iii) the sum of the area of the portions of said pair of plane electrodes facing the direction of said material is approximately equal to the contact area between said material and said sheet of insulator when said material is chucked.
2. An electrostatic device as defined in claim 1, wherein said pair of electrodes is embedded in said insulator.
3. An apparatus for dry etching of a material having at least a conductive portion and using at least a sputter

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etching apparatus, a reactive sputter etching apparatus or a plasma etching apparatus, comprising:

- (a) a supporting base, the temperature of which is maintained at a predetermined value;
- (b) an electrostatic chuck mounted on the supporting base for chucking the material to be dry etched and having,
 - (i) a sheet of insulator positioned on the top surface of said electrostatic chuck and,
 - (ii) a pair of plane electrodes positioned on the bottom surface of said sheet of insulator in close contact with said sheet, wherein said pair of plane electrodes is electrically isolated from each other, the sum of the area of the portions of said pair of plane electrodes facing the direction of said material being approximately equal to the contact area between said material and said sheet of insulator when said material is chucked, voltage being supplied between said pair of plane electrodes from an external voltage source so that said material can be chucked on said sheet of insulator; and
 - (c) an etching chamber wherein gases are applied with electric power to form a plasma for etching.
4. An apparatus as defined in claim 3, wherein said pair of electrodes is embedded in said insulator.
5. The electrostatic chucking device of claim 1 or 3, wherein the shape of each of said plane electrodes is semispherical.
6. The electrostatic chucking device of claim 1 or 3, wherein each of said plane electrodes comprises two quarters to a circle with all four quarters being positioned symmetrically about a center point.
7. The electrostatic chucking device of claim 1 or 3, wherein the shapes of each of said plane electrodes is a concentric circle.
8. The electrostatic chucking device of claim 1 or 3, wherein the thickness of the insulator is approximately 50 to 200 micrometers.
9. The electrostatic chucking device of claim 1 or 3, wherein the insulator is elastic relative to the material to be etched so that the insulator can contact closely with the material.
10. The electrostatic chucking device of claim 1 or 3, wherein the insulator is polyethylene.
11. The electrostatic chucking device of claim 1 or 3, wherein the insulator is polytetrafluoroethylene.
12. The electrostatic chucking device of claim 1 or 3, wherein the insulator is silicon gum.
13. A method for dry etching of a material having at least a conductive portion, using at least one of a sputter etching apparatus, a reactive sputter etching apparatus or a plasma etching apparatus, comprising the steps of:
 - (a) putting the material to be etched on an electrostatic device having,
 - (i) a sheet of insulator, and
 - (ii) a pair of plane electrodes positioned on the bottom surface of said sheet of insulator in close contact with said sheet, wherein said pair of plane electrodes is electrically isolated from each other, voltage being supplied between said pair of plane electrodes from an external voltage source to cause the material to be chucked on the top surface of said sheet of insulator, the electrostatic device being positioned on a supporting base, the temperature of which is maintained at a predetermined value, and the sum of the area of the portions of said pair of plane electrodes fac-

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ing the direction of said material is approximately equal to the contact area between said material and said sheet of insulator when said material is chucked,

(b) applying a voltage between said pair of plane electrodes of said electrostatic device from the external power source to cause said material to be chucked electrostatically and thereby indirectly fixed to said supporting base;

(c) introducing etching gases into the etching chamber of one of said sputter etching apparatus, said reactive sputter etching apparatus, or said plasma etching apparatus and applying an electric field to said gases by another power source to form a plasma, and

(d) etching of said material at the condition of high heat conductivity between said material and said supporting base, said high heat conductivity being obtained by the electrostatic chucking force resulting in an increase in thermal contact therebetween, whereby the temperature of said material is controlled close to said predetermined value.

14. A method for dry etching as defined in claim 2, using at least one of said sputter etching apparatus or

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said reactive sputter etching apparatus, wherein said supporting base is an electrode to which high frequency voltage is applied to form the plasma.

15. A method for dry etching as defined in claim 14 wherein said voltage of said external power source means is of direct current or of low frequency and is applied to said pair of plane electrodes through high frequency eliminating filters.

16. A method for dry etching as defined in claim 13, 14 or 15, wherein said material is etched while said material is being indirectly chucked on said supporting base by said electrostatic device.

17. A method for dry etching as defined in claim 13, 14 or 15, wherein said material is etched while said material is being indirectly chucked on said supporting base by said electrostatic device while in the vertical plane.

18. A method for dry etching as defined in claim 13, 14 or 15, wherein said material is etched while said material is being indirectly chucked on said supporting base by said electrostatic device and while being invertedly held in the horizontal plane.

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UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 4,384,918

Page 1 of 2

DATED : 5/24/83

INVENTOR(S) : NAOMICHI ABE

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

ABSTRACT

Line 4, after "on" insert --the bottom surface of--;
Line 5, after "on" delete "the bottom surface of";

Col. 1, line 25, after "etched" insert --using--;
line 42, after "electric" change "but must be
high power," to --power must be high, but--.

Col. 2, line 22, change "material" to --materials--;
line 54, after "(1)" change the semicolon (;)
to a colon (:).

Col. 3, line 4, after "other" delete --whom-- and insert
--known--;
line 11, delete "interval";
line 16, delete "side";
line 18, delete "non-".

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 4,384,918

Page 2 of 2

DATED : 5/24/83

INVENTOR(S) : NAOMICHI ABE

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Col. 4, line 26, after "wafer" delete --a--; after "including" insert --a--;
line 39, after "etching" insert a parenthesis --);
line 47, delete --sup- --;
line 48, delete --porting base,--.

Col. 5, line 35, delete "the portion of"; after "of" (second occurrence) insert --the portions of--;

Col. 7, line 15, after "is" insert --effectively--;
line 30, change "undirectly" to --indirectly--.

Col. 8, line 33, after "wafer" change "is" to --was--;
line 55, after "allowing" delete --thereby--;
after "effectively" insert --thereby--.

Col. 9, line 9, after "to" delete --the--.

Signed and Sealed this

Twenty-ninth Day of November 1983

[SEAL]

Attest:

GERALD J. MOSSINGHOFF

Attesting Officer

Commissioner of Patents and Trademarks

EXHIBIT M

United States Patent [19]

Takagi et al.

[11] Patent Number: 4,539,068

[45] Date of Patent: Sep. 3, 1985

[54] VAPOR PHASE GROWTH METHOD

[75] Inventors: Mikio Takagi, Kawasaki; Kanetake Takasaki, Tokyo; Kenji Koyama, Yokosuka, all of Japan
 [73] Assignee: Fujitsu Limited, Kawasaki, Japan

[21] Appl. No.: 412,260

[22] Filed: Aug. 27, 1982

Related U.S. Application Data

[63] Continuation of Ser. No. 264,805, May 18, 1981, abandoned, which is a continuation-in-part of Ser. No. 184,363, Sep. 5, 1980, abandoned.

[30] Foreign Application Priority Data

Sep. 20, 1979 [JP] Japan 54-121489

[51] Int. Cl.³ C30B 25/02[52] U.S. Cl. 156/614; 427/93;
427/94; 156/DIG. 64[58] Field of Search 156/614, 613, DIG. 64,
156/DIG. 99; 423/349; 148/175; 427/34, 39,
86, 94, 93, 95, 248.1, 255.2, 87; 204/192 S, 177,

164

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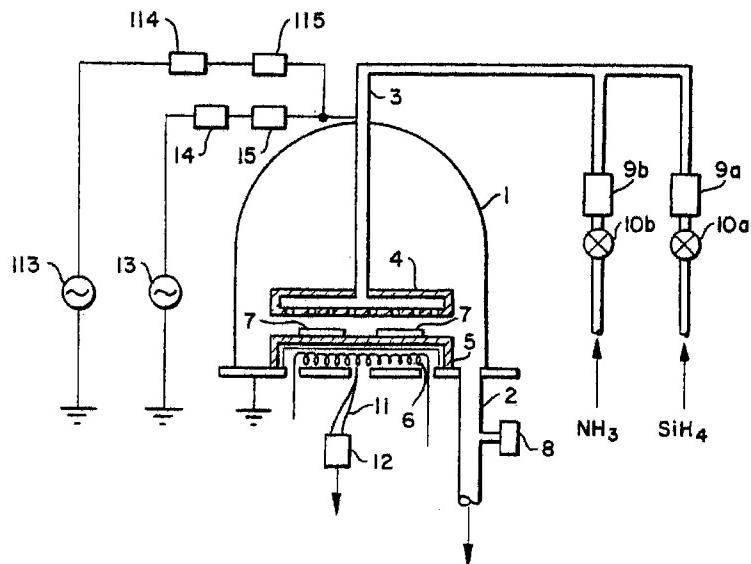
Primary Examiner—Hiram H. Bernstein

Attorney, Agent, or Firm—Staas & Halsey

[57] ABSTRACT

A plasma chemical vapor deposition method for forming a film on a substrate which is placed on one of a pair of electrodes oppositely arranged within the reaction chamber of a reactor. A plurality of power generators of different frequencies are applied to the electrodes to excite reactive gases introduced into the reaction chamber, whereby the reactive gases are transformed into a plasma and a desired film is formed on the substrate. Film with a small number of pinholes was formed at a relatively high deposition rate by combinations of power generator frequencies of, for example, 13.56 MHz and 1 MHz, 13.56 MHz and 50 KHz, and 5 MHz and 400 KHz.

3 Claims, 10 Drawing Figures



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FIG. 1.
PRIOR ART

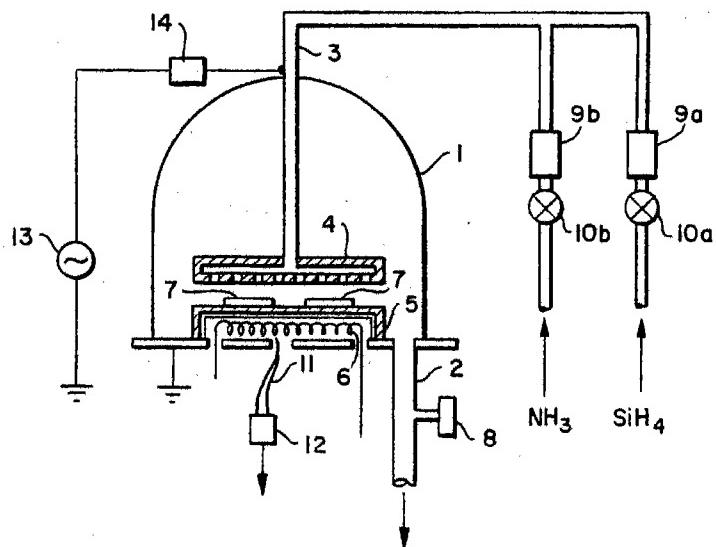
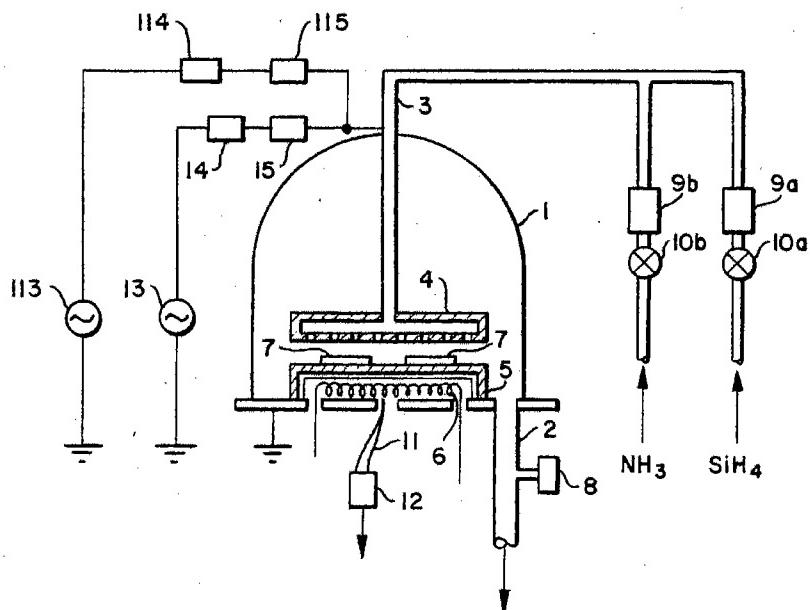


FIG. 3.

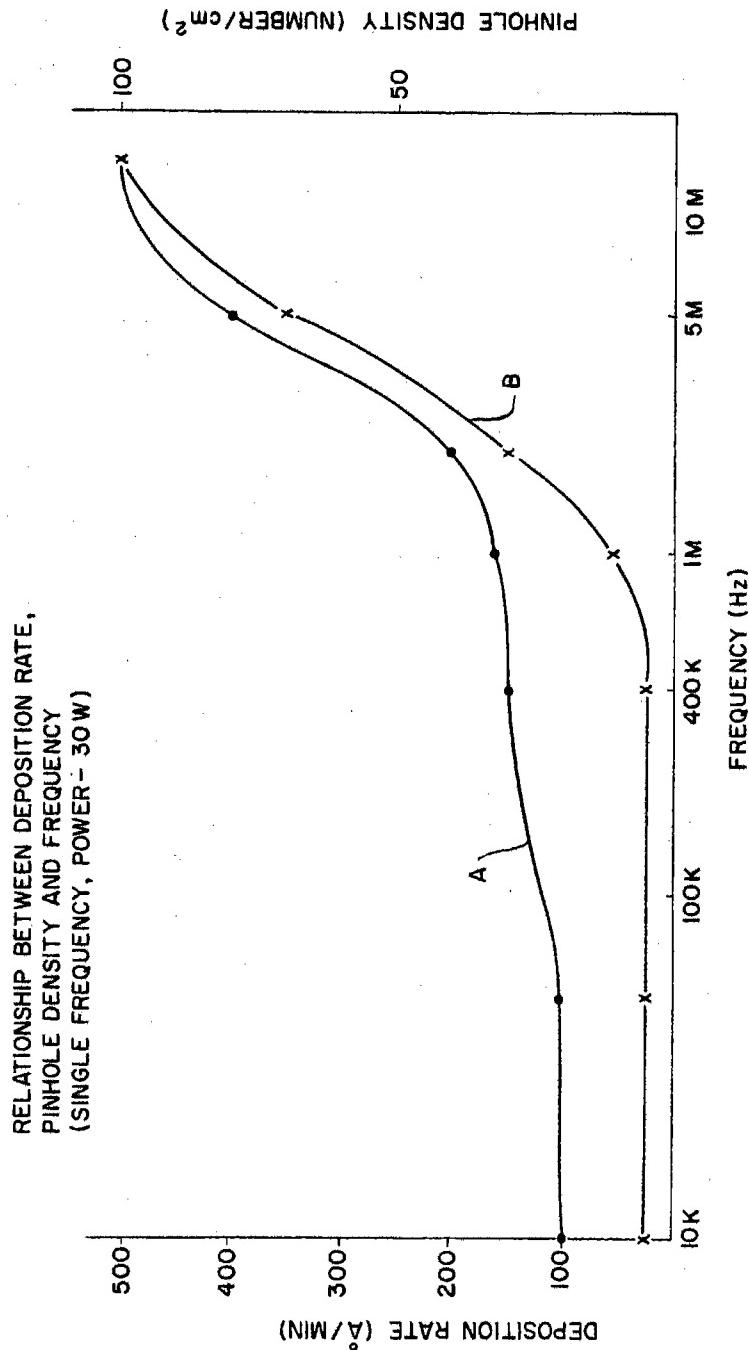


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FIG. 2.



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FIG. 4.

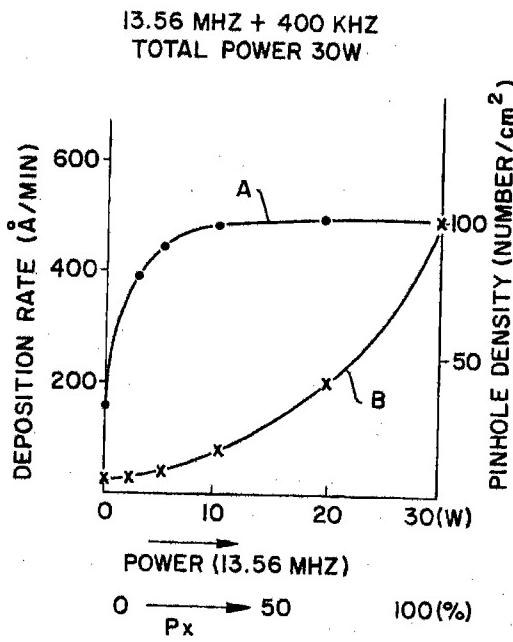


FIG. 5.

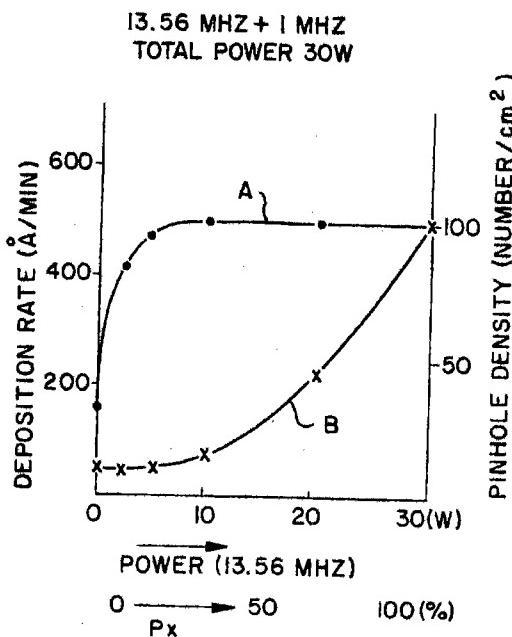


FIG. 6.

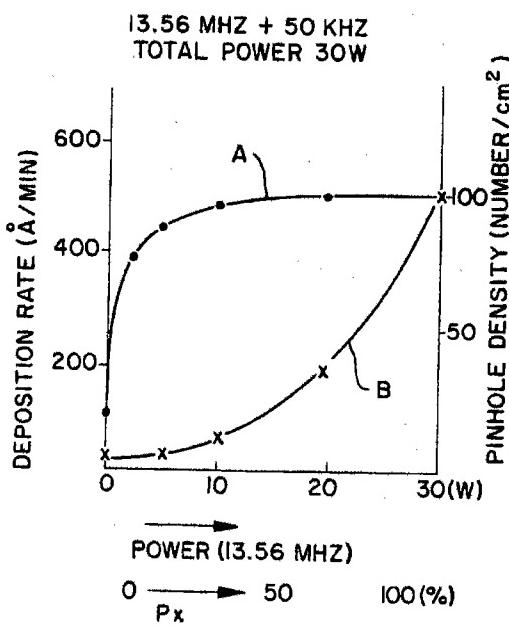
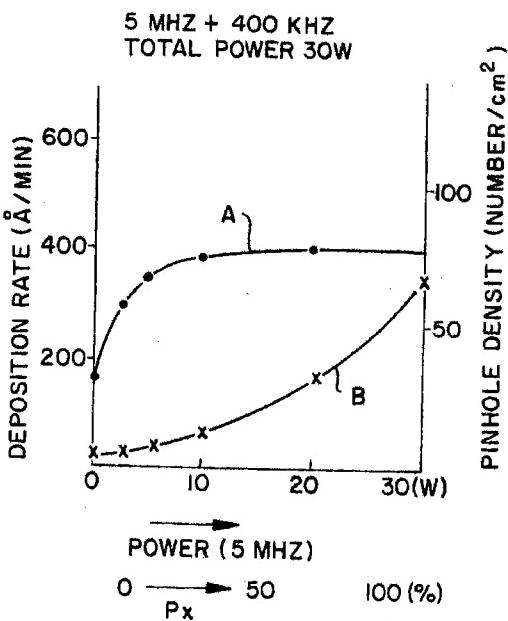


FIG. 7.



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FIG. 8.

13.56 MHZ + 5 MHZ
TOTAL POWER 30W

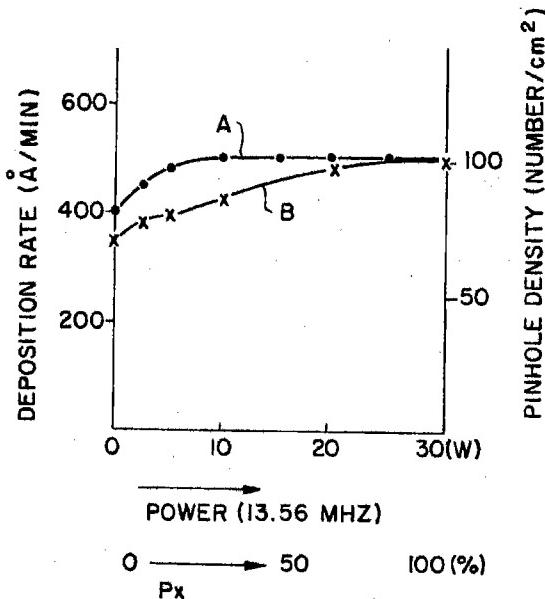
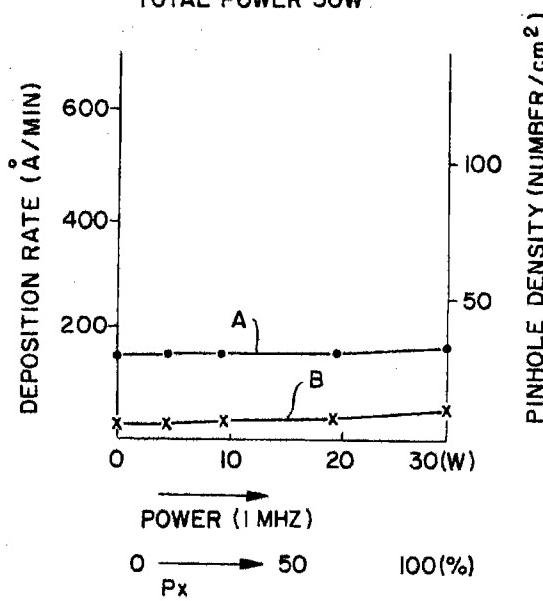


FIG. 9.

1 MHZ + 400 KHZ
TOTAL POWER 30W

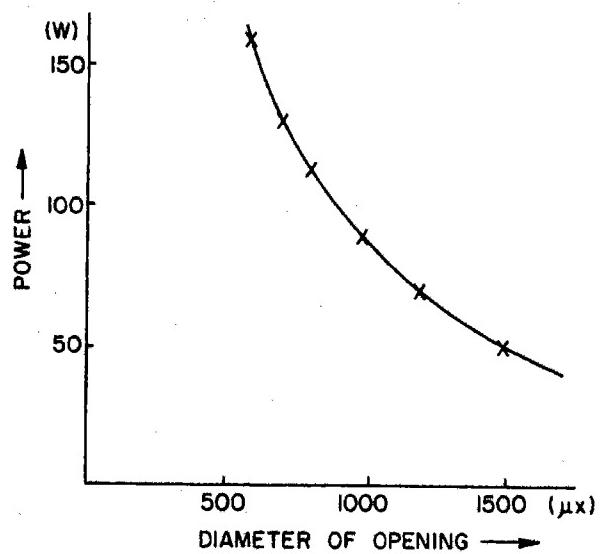


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FIG. 10.



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VAPOR PHASE GROWTH METHOD

CROSS-REFERENCE TO RELATED
APPLICATIONS

This is a continuation of Application Ser. No. 264,805, filed May 18, 1981, now abandoned, which is a continuation-in-part of Application Ser. No. 184,363, filed Sept. 5, 1980, now abandoned.

BACKGROUND OF THE INVENTION

The present invention relates to a vapor phase growth method and apparatus, and more particularly to a plasma chemical vapor deposition (CVD) method and apparatus.

In the art to which this invention pertains, the plasma chemical vapor deposition method has been widely practiced for forming a desired film on a substrate such as a semiconductor substrate. In this method, plasma is generated between oppositely arranged electrodes in a reaction chamber of a reactor, and a deposition is formed on the substrate by the chemical phase reaction of reactive gases introduced into the furnace tube.

One plasma CVD apparatus used to carry out the method of vapor phase growth mentioned above is schematically illustrated in cross-section in FIG. 1. This apparatus is of the so-called parallel plate type or condenser coupled type. If silicon-nitride film is to be attached or grown on the surface of a semiconductor substrate, for example, air is drawn out of a reaction chamber 1 made of quartz or stainless steel (in which case it must be shielded in the conventional manner) through an exhaust pipe 2 to maintain a vacuum pressure on the order of 1 Torr within the reaction chamber 1. The pressure will be indicated by a vacuum gauge 8. Monosilane (SiH_4) gas and ammonia (NH_3) gas are introduced through an inlet 3 into the reaction chamber via control taps or valves 10a, 10b and flow meters 9a, 9b. Radio frequency power generated by a generator 13 is applied, through a conventional matching box 14, between upper and lower electrodes 4 and 5 which are oppositely arranged to cause discharge therebetween. Matching box 14 is used to match the output impedance of the generator 13 to the input impedance of the apparatus within the reaction chamber 1. The lower part of the upper electrode 4 is a porous plate having openings. Lower electrode 5 is a two layer structure base made of aluminum covered stainless steel. The lower electrode 5 is heated, by a conventional heater 6, to 300° to 400° C. A standard thermocouple 11 is placed under the heater 6, and, through a suitable feedback controller 12, is connected to a conventional power source (not shown) for the heater 6. Semiconductor substrates 7 are placed parallel to each other on the lower electrode 5. Reactive gases are introduced into the reaction chamber 1 and are caused to jet onto the substrates 7, heated to 300° to 400° C., through openings in the porous plate of the upper electrode 4, the gases being excited by the discharge energy to effect vapor phase reaction. As a result, Si_3N_4 film attaches or grows on the semiconductor substrates 7.

The advantage of the above method of vapor phase growth over known ordinary chemical vapor deposition methods is that the desired film is grown on the semiconductor substrate at temperatures in the range of 300° to 400° C. compared to a temperature on the order of 850° C. employed in conventional chemical vapor deposition methods. In the manufacture of integrated

circuits, it is desired to carry out the process of manufacture after the metallization process at temperatures not exceeding 450° C. because metals having low melting points are used in the interconnection of integrated circuit elements. In the method explained above, the temperature within the reaction chamber never exceeds 450° C., so that this method satisfies the temperature requirements for the manufacture of integrated circuits.

The condition of the deposition grown depends on whether the frequency used is high or low. If a low frequency is selected, a film of high quality is produced but the deposition rate is low. In contrast, if a high frequency is selected, the deposition rate is high, but the quality of the film is not satisfactory. This is a major problem encountered in carrying out the conventional vapor phase growth method in which a radio frequency power source is utilized.

As an example of the problems mentioned above, the prior art method was carried out using the apparatus shown in FIG. 1 under a variety of conditions.

For the purpose of growing a film of Si_3N_4 as described above, a power source frequency of 400 KHz was selected. The ratio of gases introduced was set so that $\text{NH}_3/\text{SiH}_4=2$. A radio frequency power in range of 10 to 30 W was used while maintaining the vacuum pressure within the reaction chamber 1 at 1 Torr. The resulting deposition rate was 150 Å/minute. Although the deposition rate was low, a high quality Si_3N_4 film having a small number of pinholes was grown.

Under the above conditions, the power source frequency was changed to 13.56 MHz. A high deposition rate of 500 Å/minute was achieved, but there were many pinholes, hence poor film quality.

The experimental results obtained by carrying out the plasma chemical vapor deposition method by applying a single radio frequency power source, including the two examples described above, are shown graphically in FIG. 2 which shows the relationship between the frequency and the deposition rate and pinhole density. The applied power was 30 W, or the power density per unit area of the electrode was 0.3 W/cm². In FIG. 2, the abscissa represents the power frequency and the ordinates the deposition rate at left and the pinhole density at right. In FIG. 2, curve A illustrates the relationship between the power frequency and the deposition rate and curve B illustrates the relationship between the power frequency and the pinhole density.

This phenomenon is due to the high rate of growth of silicon ions and nitrogen ions or silicon radicals and nitrogen radicals which bring about not only the growth of Si_3N_4 on the surface of semiconductor substrate but also the falling down and deposition of Si_3N_4 produced through reaction in the vapor phase.

Further, if high frequency power is applied, the thermocouple 11 beneath the lower electrode 5 functions as an antenna, and thus produces noises that affect the feedback controller 12 which is liable to cause unwanted temperature rise. On the other hand, plasma generated by low frequency power is unstable. Therefore, whether high frequency or low frequency power is used, there are both advantages and disadvantages.

SUMMARY OF THE INVENTION

It is therefore an object of this invention to offer a solution to the technical problem encountered in the prior art by providing a novel method of growing a superior quality film at an efficient rate of deposition.

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In order to achieve this object, a plasma chemical vapor deposition method for forming a film on a substrate comprises the steps of: disposing a substrate in a reaction chamber, introducing reactive gases into the reaction chamber, applying electric power from a plurality of different frequency power generators to excite the reactive gases which are transformed into plasma, thereby forming a desired film on the substrate.

This together with other objects and advantages, which will become subsequently apparent, reside in the details of construction and operation as more fully hereinafter described and claimed, reference being had to the accompanying drawings forming a part hereof, wherein like numerals refer to like parts throughout.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic cross-sectional view illustrating an apparatus for carrying out a prior art plasma chemical vapor deposition method;

FIG. 2 is a graph illustrating the relationship between the radio frequency power source frequency (Hz) and the deposition rate and pinhole density (expressed in terms of the number of pinholes per unit area);

FIG. 3 is a schematic cross-sectional view illustrating an apparatus for carrying out the plasma chemical vapor deposition method of the present invention;

FIG. 4 is a graphic illustration of the relationship between the applied electric power and the deposition rate and pinhole density (expressed by the number of pinholes per unit area) for the preferred embodiment of the present invention;

FIGS. 5, 6 and 7 are graphic illustrations similar to that of FIG. 4 for alternative embodiments of the present invention;

FIGS. 8 and 9 are graphic illustrations, similar to that of FIG. 4, which illustrate two examples of deposition methods providing unsatisfactory results; and

FIG. 10 is a graph illustrating the relationship between the diameter of the openings provided in the electrode 4 and the arc discharge starting power.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In the present invention, electric power is applied simultaneously from a high frequency power source 45 and a low frequency power source in order to overcome the technical problems described above. The apparatus for carrying out the method of the present invention is schematically shown in FIG. 3 in cross-section.

A generator 13 generates 5 W of power (or a power density of 0.05 W per unit area of the electrode) at 13.56 MHz which is applied to upper and lower electrodes 4 and 5 through a matching box 14 and a conventional high-pass filter 15 which cuts off frequencies lower than 5 MHz. Likewise, a generator 113 generates 25 W of power (or a power density of 0.25 W per unit area of the electrode) at 400 KHz which is similarly applied to upper and lower electrodes 4 and 5 through a conventional matching box 114 and a conventional low-pass filter 115 which cuts off frequencies higher than 1 MHz. Thus, two frequencies are superimposed or mixed to generate 30 W of power to cause electric discharge.

When the diameter of the openings of the electrode 4 exceeds a certain value within the pressure range (0.1 to 65 2 Torr) of the reaction gas SiH₄+NH₃ used for the reaction in the embodiment of the present invention using the vapor growth apparatus shown in FIG. 3, an

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arc discharge is generated in the direction of the electrode 5 at the edge of the openings. Therefore, the reaction gas will partially react in the vicinity of the opening and the substances generated by this reaction will fall on the semiconductor substrate 7. These substances have a large grainsize and low adherence to the semiconductor substrate 7. For this reason, when these substances are mixed with the substances generated by the reaction in the vicinity of the surface of the semiconductor substrate 7, namely with the silicon nitride generated by the normal vapor phase reaction, the overall film quality of the silicon nitride film is degraded. Therefore, generation of this arc discharge is not desirable. This arc discharge is generated when each opening occupies a large area of the electrode 4, because the electric field distribution at the surface facing the electrode 5 becomes unequal and the electric fields are concentrated at the edge of each opening. The inventors of the present invention have found the arc discharge is not generated when the diameter of the openings provided on the electrode 4 is 500 μm or less.

FIG. 10 is a graph illustrating the relationship between the diameter of the above-mentioned openings and the arc discharge starting power. As is clear from FIG. 10, when the diameter of the openings is 500 μm or less, the arc discharge is not generated. On the other hand, it is difficult to obtain an opening diameter of 200 μm or less due to the difficulties presented in machining such a small opening. Thus, in the present invention, the diameter of the openings provided on the electrode 4 is selected to be within the range of from 200 to 500 μm. The openings are arranged in the form of a matrix on the surface of the electrode 4 facing the electrode 5, with a spacing of 3 mm. In addition, when the reaction gas SiH₄+N₂ (instead of SiH₄+NH₃) is used as the reaction gas for generating the silicon nitride film, generation of the arc discharge is more efficiently suppressed. In this case, the arc discharge can also be suppressed to a certain extent when argon (Ar) gas is used as the carrier gas.

By applying the radio frequency power as described above, the film obtained has only the advantages (and none of the disadvantages) found when using the two frequencies alone.

FIG. 4 is a graph illustrating the relationship between the electric power (at 13.56 MHz), the power ratio Px of the two frequencies, and the deposition rate (Å/minute) and pinhole density (number of pinholes/cm²) in growing a film of Si₃N₄, in the manner described above, 50 using the apparatus of FIG. 3. In FIG. 4, curve A illustrates the relationship between the power (or power ratio) and deposition rate and curve B illustrates the relationship between the power (or power ratio) and pinhole density. The abscissa power ratio Px is expressed by

$$Px = \frac{\text{power at 13.56 MHz frequency}}{(\text{power at 13.56 MHz frequency}) + (\text{power at 400 KHz frequency})} \times 100 (\%)$$

The total power was maintained at a constant value of 30 W, or power density of 0.3 W/cm² as described above.

As will be understood from an examination of the graph of FIG. 4, a relatively high deposition rate of 400 Å/minute is obtained with a relatively small pinhole density of 7/cm² to 15/cm² when the electric power at 13.56 MHz is approximately 2.5 to 10 W, (a power

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density of $0.025/\text{cm}^2$ to $0.1/\text{cm}^2$) and that at 400 KHz is approximately 27.5 to 20 W (a power density of 0.275 W/cm^2 to 0.2 W/cm^2). In this situation, the power ratio Px is approximately 8.3 to 33.3%. Further embodiments of the invention will be described hereinafter.

Three embodiments of the present invention are graphically depicted in FIGS. 5, 6 and 7. In all cases, a total power of 30 W (a power density per unit area of electrode is $0.3 \text{ W}/\text{cm}^2$) is applied. In each of FIGS. 5, 6 and 7, the ordinates represent the deposition rate at left and the pinhole density (the number of pinholes per unit area of film grown) at right. In FIG. 5, curve A illustrates the relationship between the power (or power ratio) and deposition rate and curve B illustrates the relationship between the power (or power ratio) and pinhole density. The abscissa represents the power as follows:

- in FIG. 5, the power and the power ratio from the 13.56 MHz generator;
- in FIG. 6, the power and the power ratio from the 13.56 MHz generator; and
- in FIG. 7, the power and the power ratio from the 5 MHz generator.

The value of the power and the power ratio from the other frequency power source is obtained in each case by subtracting the values represented on the abscissa from 30 W and 100%, respectively.

Good results, namely a film with a small number of pinholes at a relatively high deposition rate, are obtained in each of these embodiments when the power from the high frequency generator is on the order of 2.5 to 10 W (corresponding to a power density on the order of 0.025 to 0.1 W per unit area of the electrode and a power ratio on the order of 8.3 to 33.3%).

In contrast to the above-described embodiments, two examples illustrated in FIGS. 8 and 9 show the limitations of the deposition rate and pinhole density.

FIG. 8 illustrates a situation in which (a power density of 0.3 W per unit area of the electrode) is applied from a 13.56 MHz power source and a 5 MHz power source. As is apparent from the graph, high deposition rates (curve A) are prevalent but pinhole densities (curve B) are high.

FIG. 9 illustrates a situation in which a total power of 30 W (or power density of 0.3 W per unit area of the electrode), is applied from a 1 MHz power source and a 400 KHz power source. The results indicate that pinhole densities (curve B) are low, but deposition rates (curve A) are almost constantly low.

The results of mixing power sources of two different frequencies are enumerated below:

- (1) Pinhole density is high (70 pinholes per unit area of film grown) when power sources having frequencies higher than 5 MHz are mixed.
- (2) Deposition rate is not improved (less than 200 Å/minute) if power sources having frequencies lower than 1 MHz are mixed.
- (3) If a 5 MHz frequency power source and a power source having a frequency lower than 1 MHz are mixed, the result is the same as when a 13.56 MHz power source and a 1 MHz power source are mixed.
- (4) In order to decrease the pinhole density (less than 15 pinholes per unit area of film grown), the lower frequency power source must be maintained less than or equal to 1 MHz.
- (5) In order to increase the deposition rate (300 Å/minute or more), the higher frequency power

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source must be maintained greater than or equal to 5 MHz.

As will be understood from the foregoing description of embodiment concerning the Si_3N_4 film, chemical vapor deposition film of good quality is grown without impairing the yield by properly selecting the ratio of high frequency and low frequency power sources.

Therefore, CVD film of good quality can be grown at a low cost according to the method of the present invention. It is apparent that the invention contributes substantially not only in the manufacture of electronic components such as semiconductor chips, but also in the development of the electronic industry.

It should be noted that, although the above embodiments concern a method of forming Si_3N_4 films, the method of the present invention is not limited thereto and may be used to grow films of silicon dioxide (SiO_2), amorphous silicon, and phosphosilicate glass. Furthermore, although the above embodiment was explained with reference to the condenser coupled type plasma CVD apparatus, the method of the present invention is not limited thereto and it is applicable to the well known inductive coupling type plasma CVD apparatus.

The many features and advantages of the invention are apparent from the detailed specification and thus it is intended by the appended claims to cover all such features and advantages of the system which fall within the true spirit and scope of the invention. Further, since numerous modifications and changes will readily occur to those skilled in the art, it is not desired to limit the invention to the exact construction and operation shown and described, and accordingly all suitable modifications and equivalents may be resorted to, falling within the scope of the invention.

What is claimed is:

1. A method of plasma chemical vapor deposition for forming a film on a substrate, comprising the steps of: disposing the substrate in a reaction chamber having a pair of electrodes; introducing reactive gases into the reaction chamber; and simultaneously applying a plurality of electric power sources of different frequencies to the pair of electrodes to excite the reactive gases which are transformed into a plasma, the plurality of electric power sources of different frequencies including a first electric power source having a first frequency and a second electric power source having a second frequency, the first frequency providing a high deposition rate relative to the second frequency, the second frequency producing a reduced number of pinholes in the film relative to the first frequency; and depositing the film, having the reduced number of pinholes, on the substrate from the plasma generated by simultaneously applying the plurality of electric sources of different frequencies.
2. The method as set forth in claim 1, wherein the first electric power source comprises a high frequency power source having a frequency higher than 5 MHz and wherein the second electric power source comprises a low frequency power source having a frequency below 1 MHz.
3. The method as set forth in claim 2, wherein the electric power applying step comprises mixing the outputs of the plurality of electric power sources and applying the mixed power to the pair of electrodes, the power ratio of the high frequency power source to the total power applied being on the order of 8.3 to 33.3%.

* * * *

EXHIBIT N



US005397432A

United States Patent [19]

Konno et al.

[11] Patent Number: 5,397,432

[45] Date of Patent: Mar. 14, 1995

[54] METHOD FOR PRODUCING SEMICONDUCTOR INTEGRATED CIRCUITS AND APPARATUS USED IN SUCH METHOD

[75] Inventors: Jun-ichi Konno, Kuwana; Keisuke Shinagawa, Kawasaki; Toshiyuki Ishida, Kawasaki; Takahiro Ito, Kawasaki; Tetsuo Kondo, Kawasaki; Fukashi Harada, Kuwana; Shuzo Fujimura, Tokyo, all of Japan

[73] Assignee: Fujitsu Limited, Kawasaki, Japan

[21] Appl. No.: 743,383

[22] PCT Filed: Jun. 26, 1991

[86] PCT No.: PCT/JP91/00861

§ 371 Date: Aug. 21, 1991

§ 102(e) Date: Aug. 21, 1991

[87] PCT Pub. No.: WO92/00601

PCT Pub. Date: Jan. 9, 1992

[30] Foreign Application Priority Data

Jun. 27, 1990 [JP] Japan 2-171791

[51] Int. Cl. H01L 21/00

[52] U.S. Cl. 156/665; 156/643;

156/646; 134/1

[58] Field of Search 156/643, 646, 664, 665, 156/666; 134/1

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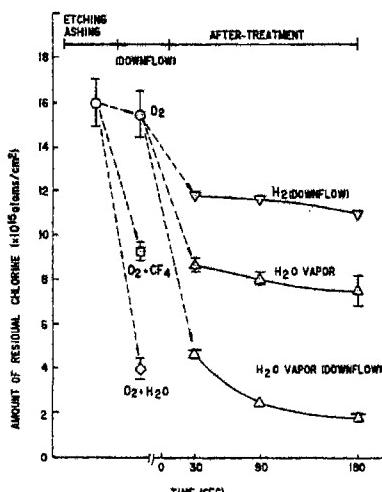
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Primary Examiner—R. Bruce Breneman
Assistant Examiner—George Goudreau
Attorney, Agent, or Firm—Nikaido, Marmelstein,
Murray & Oram

[57] ABSTRACT

To prevent after-corrosion of wiring or electrodes formed by patterning films of aluminum or an alloy thereof by reactive ion etching (RIE) using an etchant containing chlorine gas or its gaseous compounds, residual chlorine on the surface of the wiring or electrodes is removed by exposing it to a plasma generated in an atmosphere containing water vapor or to neutral active species extracted from the plasma. This treatment is performed either at the same time or after an ashing operation, an operation for removing a resist mask used in the aforesaid RIE by adding water vapor to an atmosphere containing oxygen. To perform the latter separate treatment, an automatic processing system is disclosed in which an after-treatment apparatus for removing residual chlorine is connected, via a second load lock chamber, to an ashing apparatus connected to a RIE apparatus by a load lock chamber which is capable of making a vacuum.

19 Claims, 6 Drawing Sheets



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FIG.1(a)

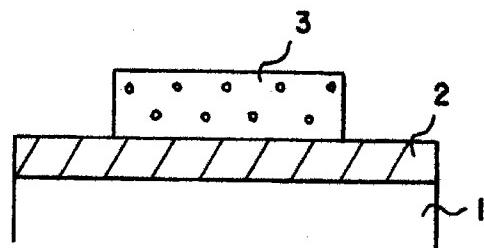


FIG.1(b)

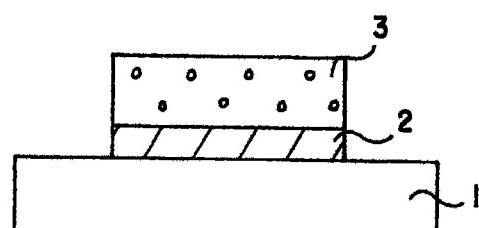


FIG.1(c)

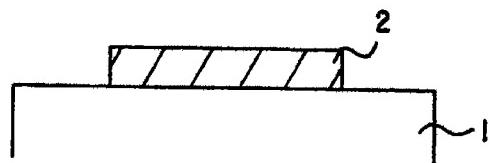
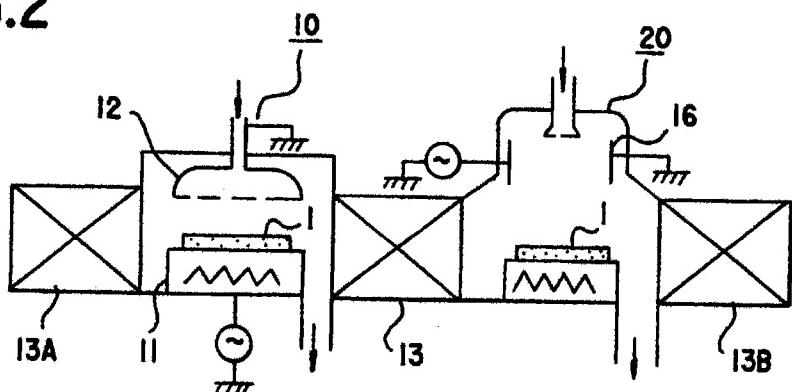


FIG.2



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FIG.3(a)

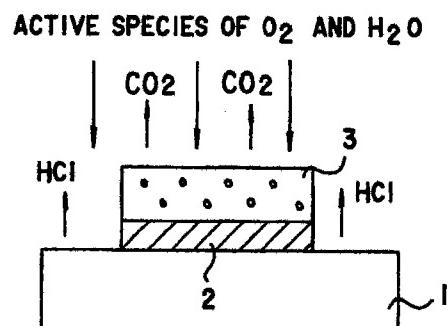


FIG.3(b)

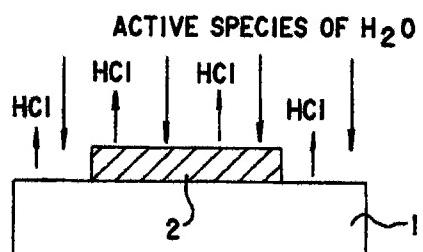
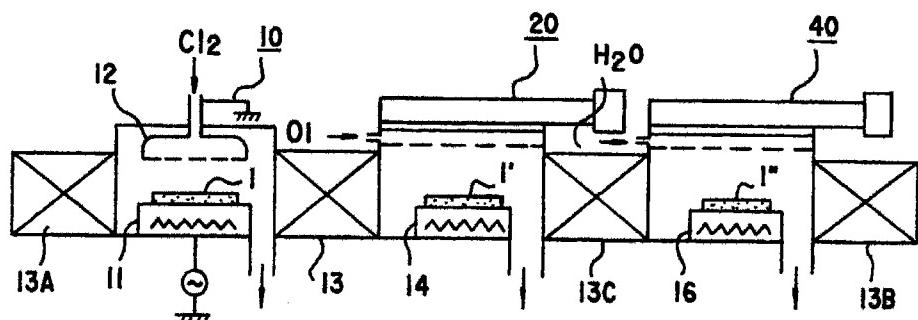


FIG.4



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FIG.5(a)

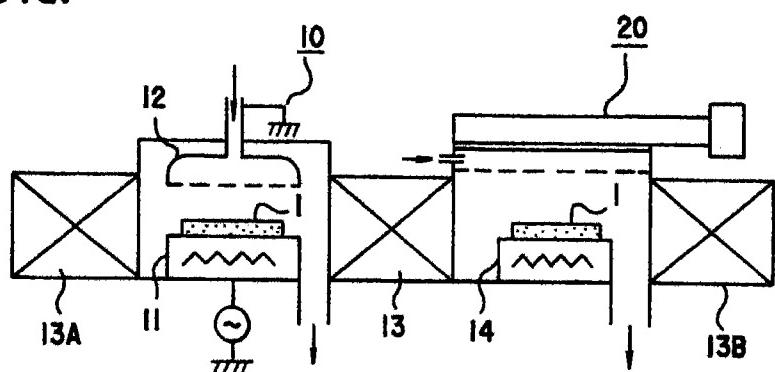
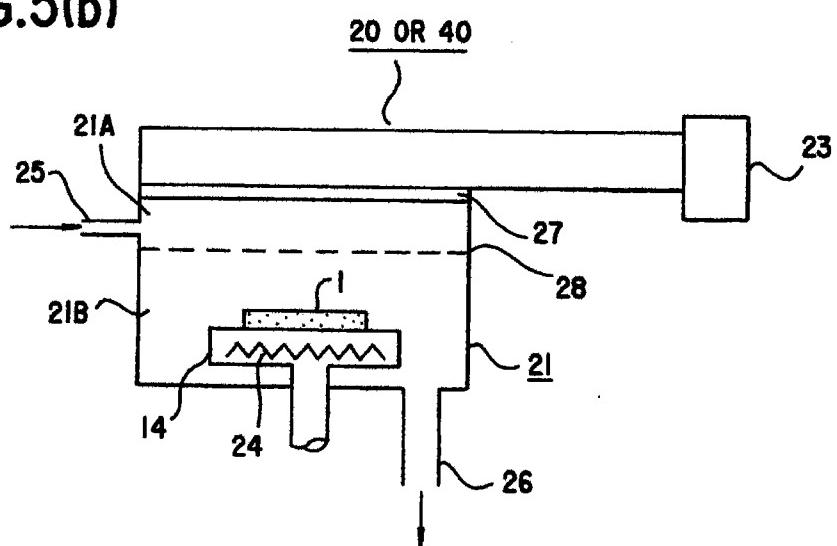


FIG.5(b)



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FIG.6

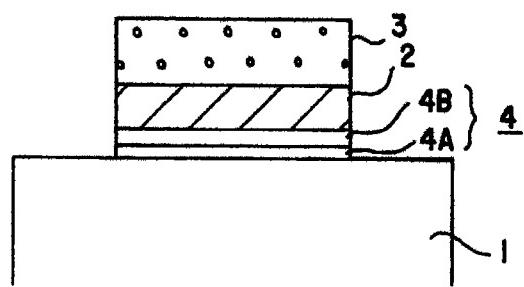
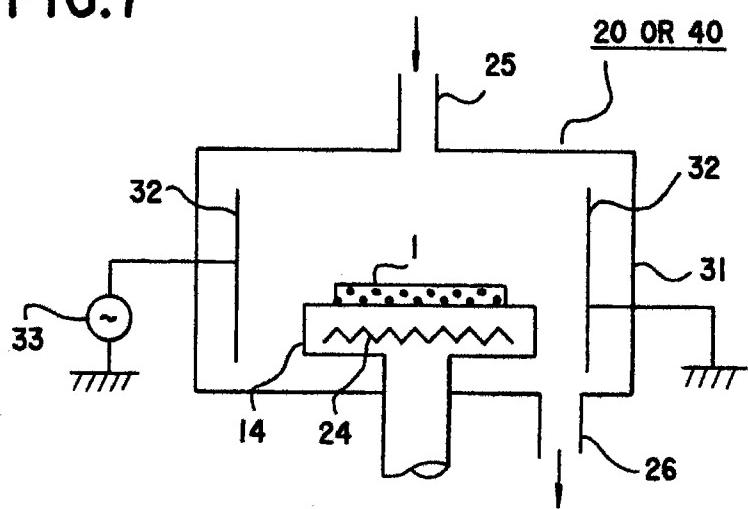


FIG.7



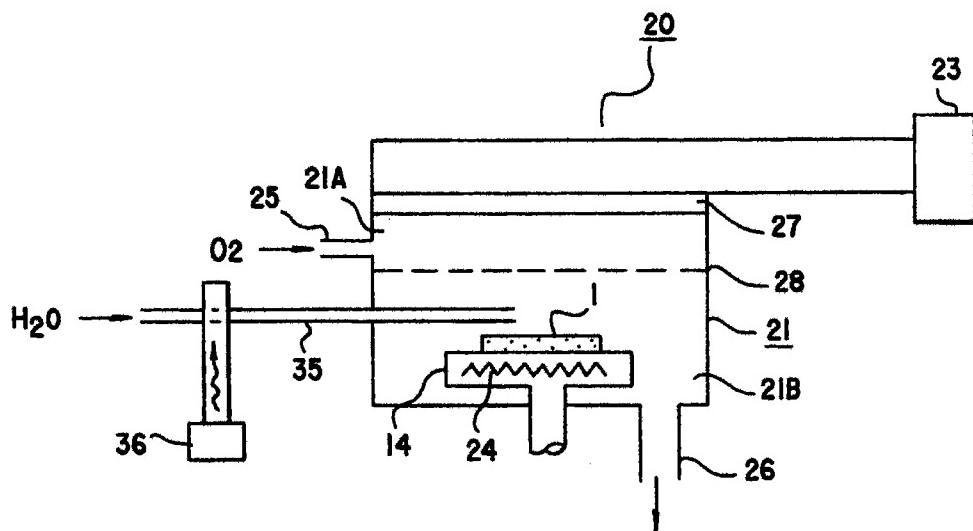
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FIG.8



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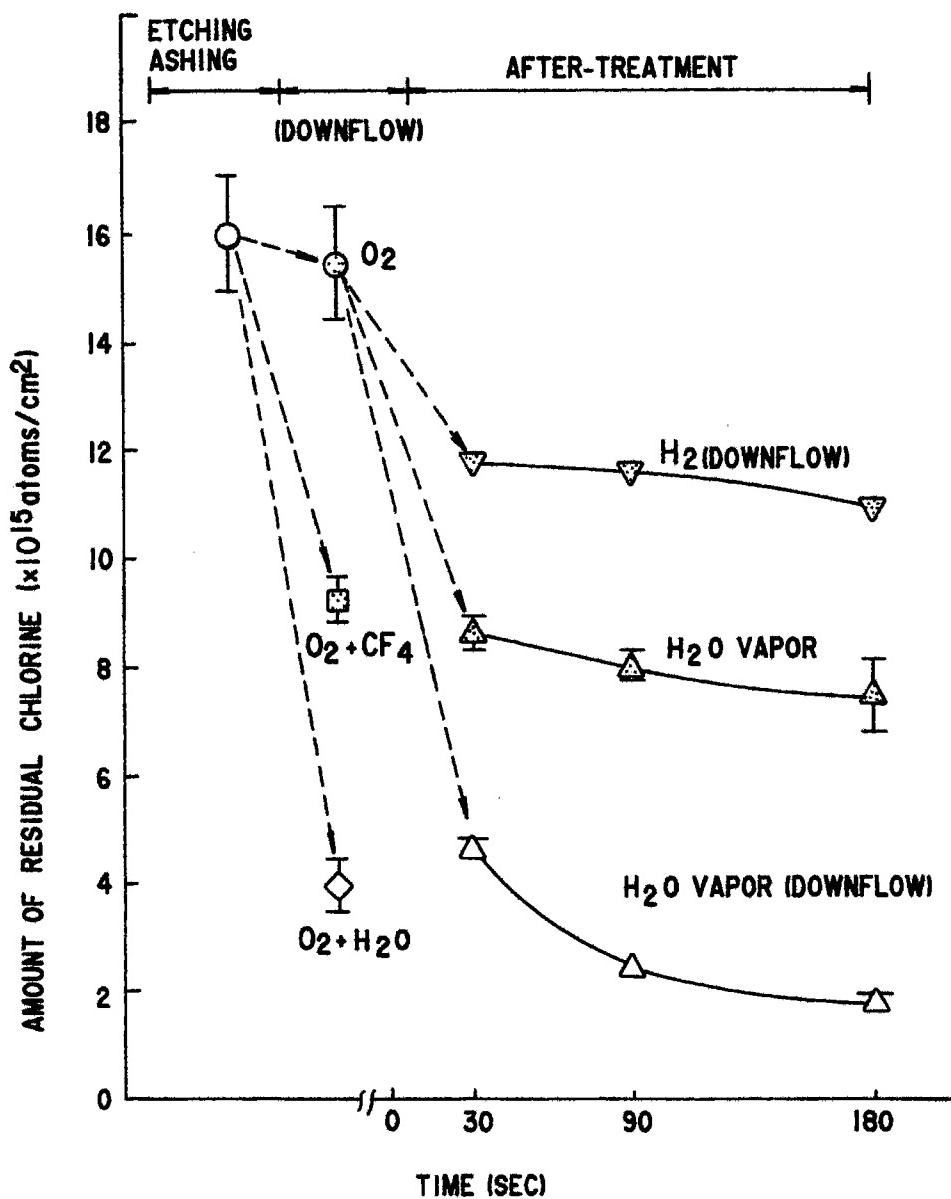


FIG.9